RETHINKING EXPOSURE ASSESSMENT USING DOSE FRACTIONS

William W Nazaroff

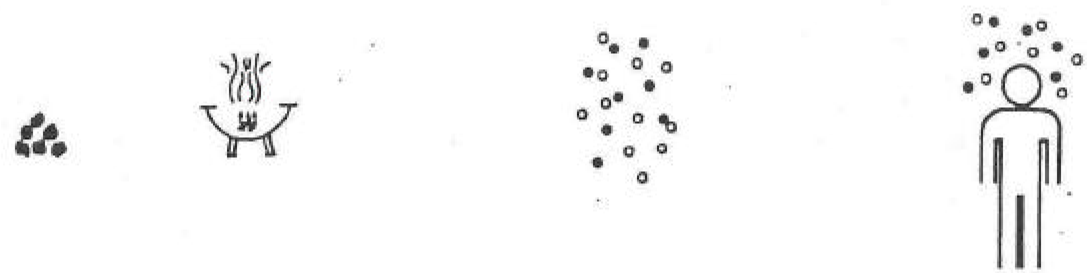
Department of Civil and Environmental Engineering, University of California, Berkeley, CA 94720-1710

Chairman Air Pollution Seminar Series
California Air Resources Board
Sacramento

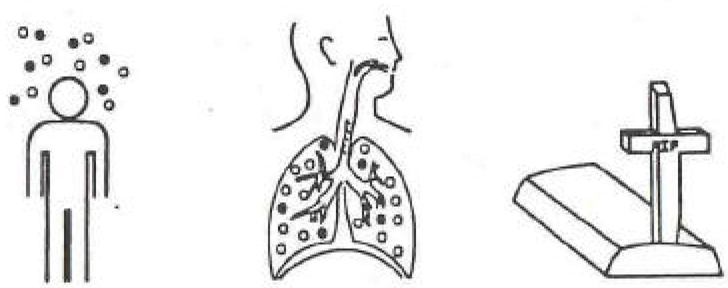
May 23, 2001

AIR POLLUTION: SOURCE-EFFECTS PARADIGM

source → emissions → concentration → exposure →



→ exposure → dose → health effects



source: KR Smith, *Ann. Rev. Energy Environ.* **18**: 529, 1993.

APPROACHES TO DETERMINING EXPOSURE

- Personal monitoring
- Stochastic (Monte-Carlo) modeling
  - microenvironmental monitoring
  - activity pattern data
- Deterministic modeling
  - urban airshed model
  - plume model
  - indoor microenvironment model

A KEY LIMITATION OF EXISTING APPROACHES

How much do different sources contribute to personal exposure to air pollutants?

ISSUES IN THE LANDSCAPE

- Antiterrorism assessments
- Tuberculosis control in health-care facilities
- "Cigarette equivalents" for ETS exposure
- Health-risk assessment for air toxics
- Teaching air quality engineering: importance of indoor air

DOSE FRACTION CONCEPT

$$iDf = \frac{\text{mass inhaled (one person)}}{\text{mass emitted}}$$

$$\boxed{Df = \frac{\text{mass inhaled (by all exposed persons)}}{\text{mass emitted}}}$$

DOSE FRACTION VIRTUES

- Intuitive meaning
- Focus attention on source-to-dose relationships
- Flexible and extensible concept

EXPOSURE MODELING USING DOSE FRACTIONS

"A model is an imitation of reality which stresses those aspects that are assumed to be important and omits all properties considered to be nonessential."

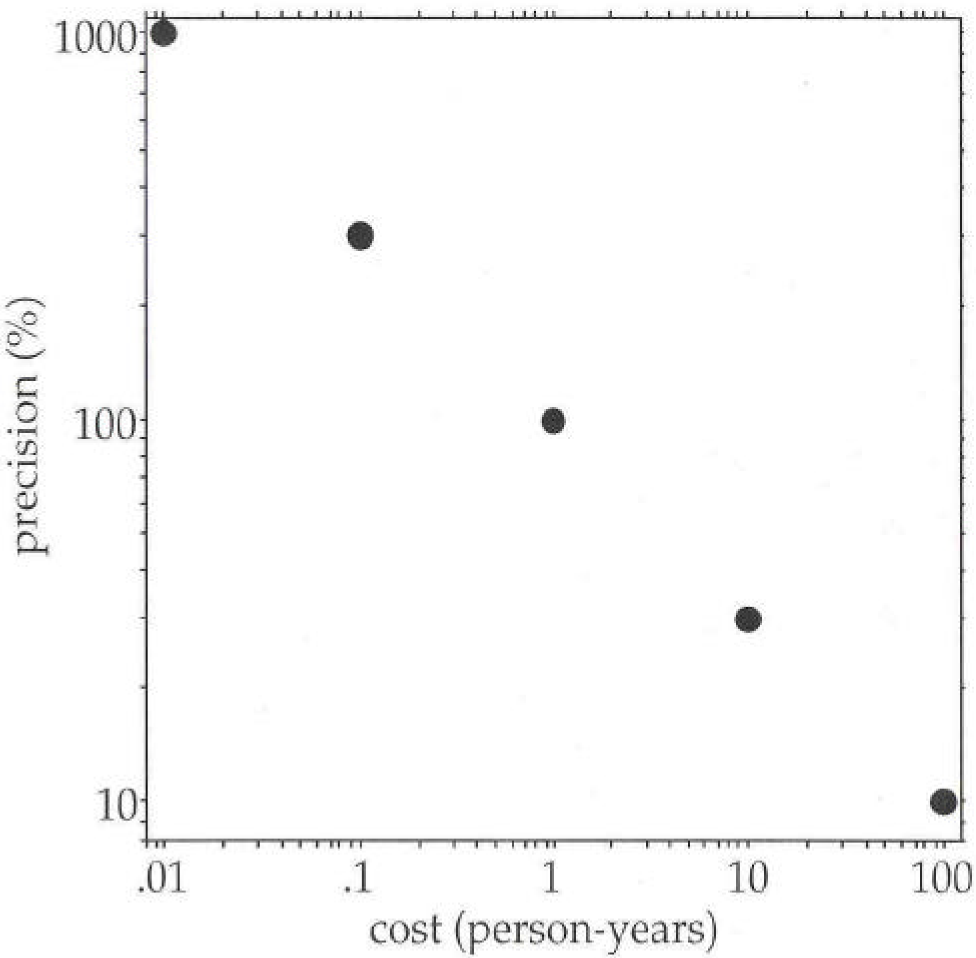
RP Schwarzenbach et al., *Environmental Organic Chemistry*, Wiley, New York, 1993.

IN DEFENSE OF SIMPLIFICATION

"The spherical cow approach to problem solving involves the stripping away of unnecessary detail, so that only the essentials remain."

J Harte, *Consider a Spherical Cow: A Course in Environmental Problem Solving*, University Science Books, Mill Valley, 1988.

ENVIRONMENTAL MODELING: COST VS. PRECISION



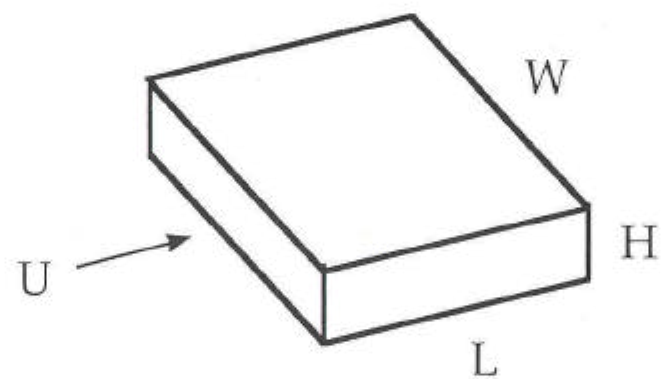
CASE STUDY

- South Coast Air Basin (SoCAB)
- Motor vehicles: cars & light/medium-duty trucks
- Environmental tobacco smoke in residences
- Daily inhaled dose, summed over population
- Species: selected HAPs, criteria pollutants, carcinogens

DOSE FRACTION – WELL-MIXED URBAN AIR BASIN

$$Df = \frac{PLQ_B}{HU}$$

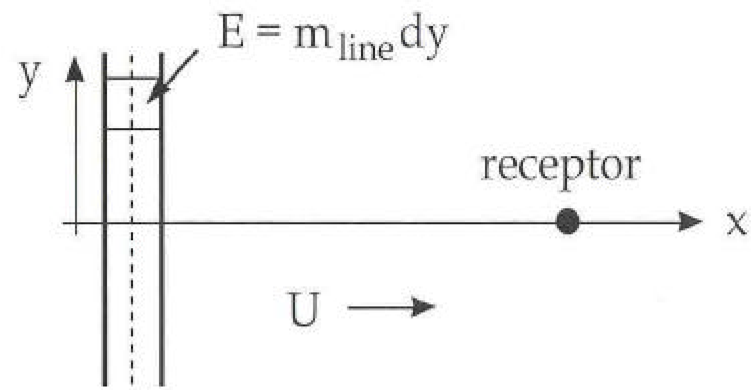
- Symbols: P = population density (m^{-2}); L = air basin dimension in direction of wind (m); Q_B = population average breathing rate ($m^3\ s^{-1}$); H = mixing height of air basin (m); U = wind speed ($m\ s^{-1}$)



DOSE FRACTION – LINE SOURCE, GROUND LEVEL

$$\boxed{C = \frac{\sqrt{2}m_{line}}{\sqrt{\pi}U\sigma_z}}$$

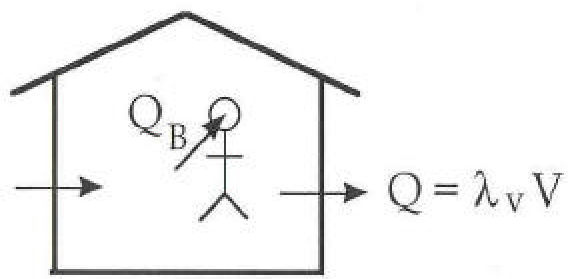
- Symbols: C = ground-level concentration increment from line source ($\mu g\ m^{-3}$); m_{line} = emission rate per length of line ($\mu g\ m^{-1}\ s^{-1}$); U= wind speed ($m\ s^{-1}$); σ_z = vertical dispersion coefficient (m)



DOSE FRACTION – INDOOR EMISSIONS

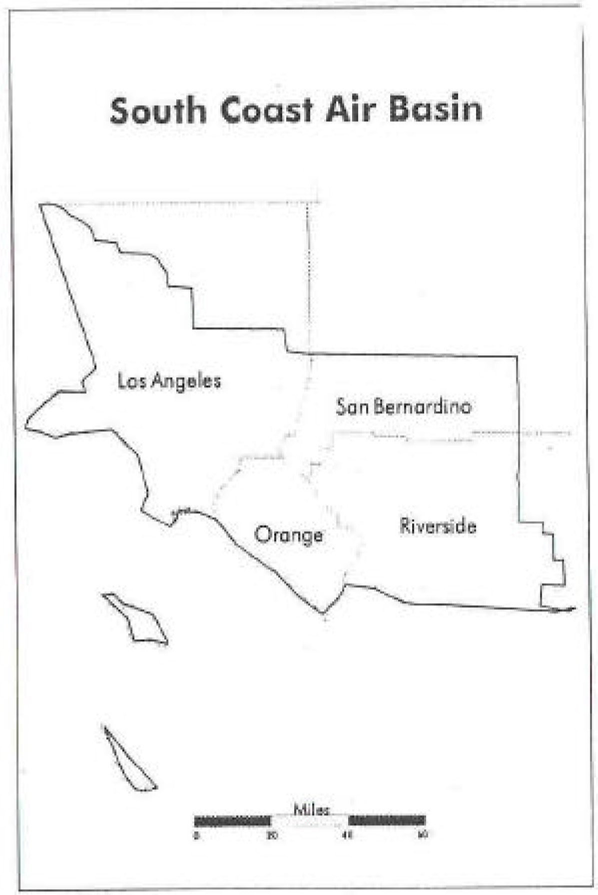
$$\boxed{Df = \frac{NQ_B}{\lambda_v V}}$$

- Symbols: N= occupancy (–); Q_B = average breathing rate of occupants ($m^3\ h^{-1}$); λ_v = air-exchange rate (h^{-1}); V= building volume (m^3)



APPLICATION: SOUTH-COAST AIR BASIN (SoCAB)

- 6350 square miles
- 14 million people
- 310 million miles/day
- 1.9 million smokers
- 32 million cigarettes/day



MOTOR VEHICLE EMISSIONS

- Fuel-based emissions inventory (Harley and coworkers)
  - sales-tax records for fuel use
  - remote sensing for CO and VOC emissions
  - tunnel studies to apportion VOC among species

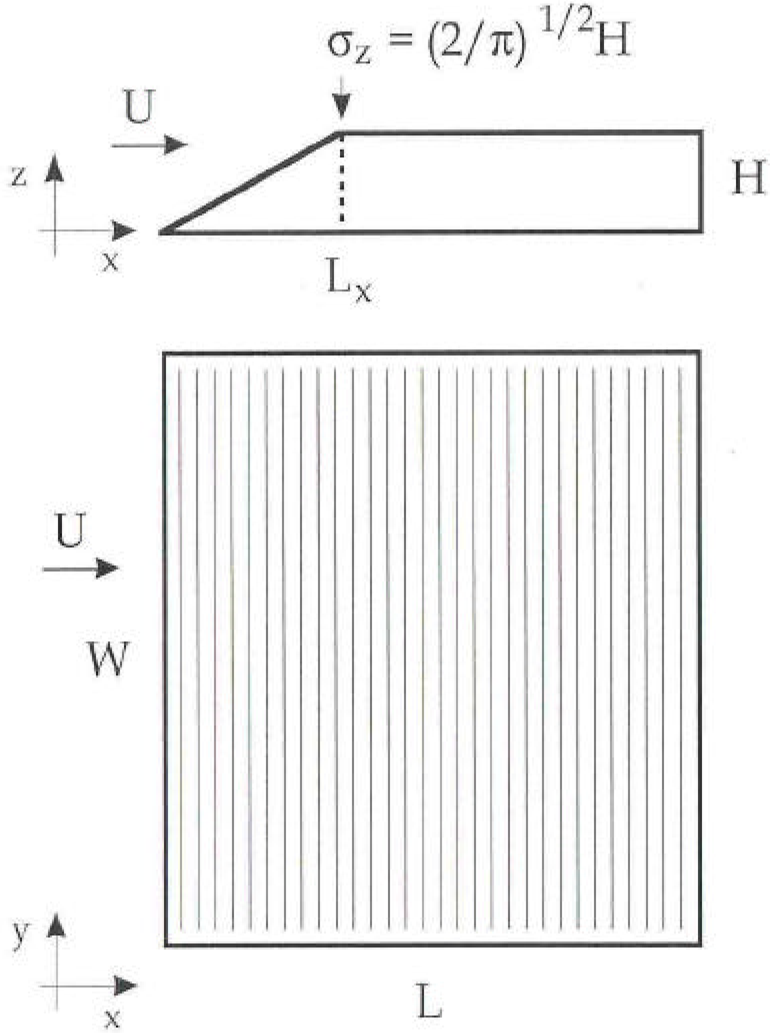
- Key results
  - 59 million L/day by cars & light/medium-duty trucks
  - 60,000 emission measurements at 35 sites in SoCAB
  - Average CO emissions: 80 ± 7 g/L
  - Average VOC emissions: 9.3 ± 1.5 g/L

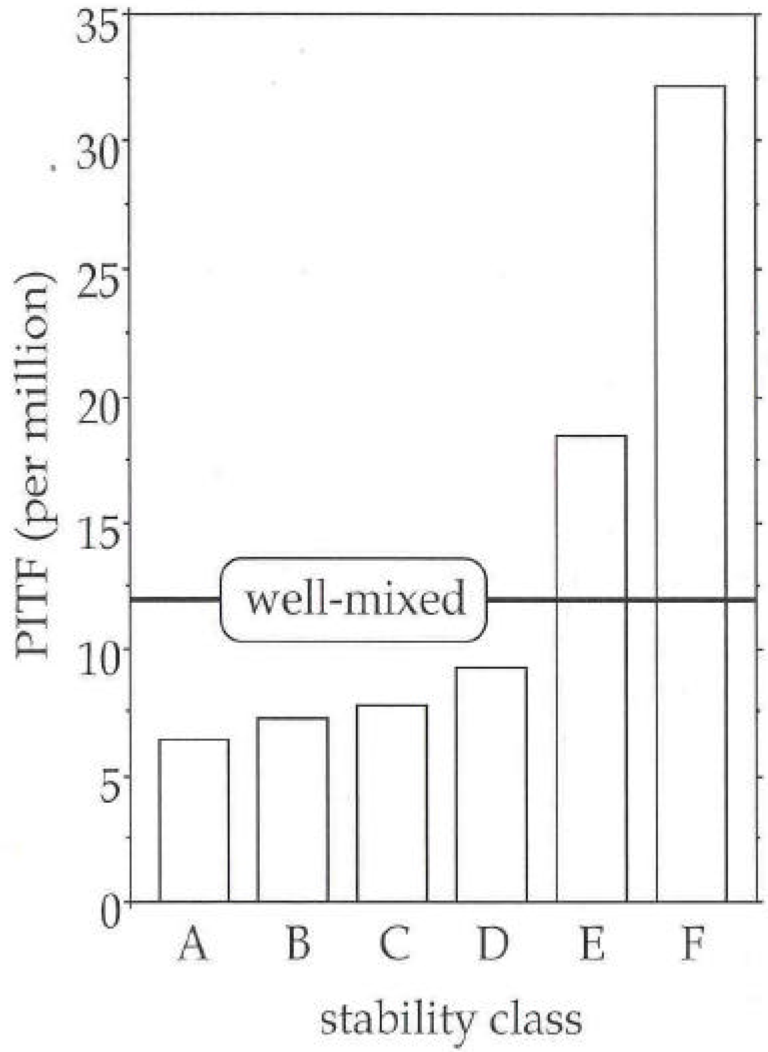
DOSE FRACTION FOR MOTOR VEHICLES: SoCAB

- Populated area: 130 km $\times$ 130 km
- Population density: 820 persons km^{-2}
- Mean wind speed (TMY): 3.6 m/s (NREL, 1995)
- Harmonic mean mixing height (1984 & 1991): 340 m
- Breathing rate: 12 m^3/d (Layton, 1993)
- Result based on well-mixed air basin

$$\boxed{Df = 12 \times 10^{-6}}$$

WELL-MIXED BASIN vs. DISTRIBUTED LINE SOURCES





ENVIRONMENTAL TOBACCO SMOKE EMISSIONS

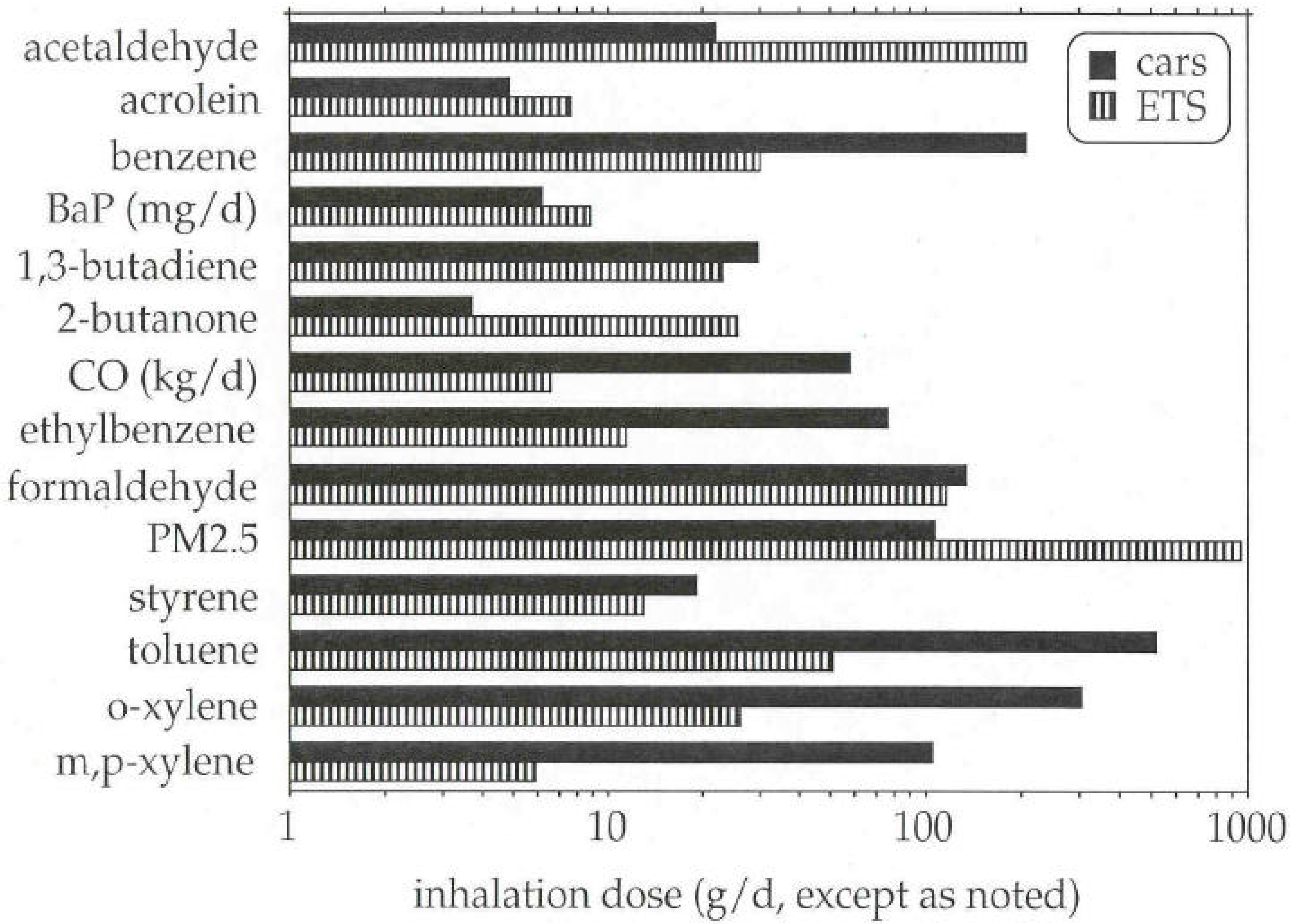
- Cigarette consumption data for CA (BRFSS)
  - smoking prevalence: 18% of adults & 6% of adolescents
  - cigarette consumption rate: 17 cigs d^{-1}
  - assume 50% of cigarettes are smoked inside residence
- Neglect exposure to other cigarettes
- ETS emission factors from chamber studies:
  - Daisey et al., *JEAEE*, **8**, 313-334, 1998
  - Martin et al., *Environ. Int.*, **23**, 75-90, 1997

DOSE FRACTION FOR ETS: SoCAB

- Housing data
  - average occupancy: N = 2.8 persons (census)
  - volume: V = 283 m^3 (Wilson et al., 1996)
  - air-exchange rate: $\lambda_v = 0.9\ h^{-1}$ (Wilson et al., 1996)
- Breathing rate: 0.5 $m^3\ h^{-1}$ (Layton, 1993)

$$\boxed{Df = 5.5 \times 10^{-3}}$$

INHALATION DOSES: VEHICLES vs. TOBACCO



WHICH CONTRIBUTES MORE TO EXPOSURE?

- Motor vehicles dominate ($\geq 3 \times$)
  - carbon monoxide
  - BTEX compounds
- Environmental tobacco smoke dominates ($\geq 3 \times$)
  - acetaldehyde
  - 2-butanone
  - $PM_{2.5}$
- Source classes have similar contributions (within $3 \times$)
  - benzo(a)pyrene
  - 1,3-butadiene
  - formaldehyde
  - styrene

THE RULE OF 1000 *

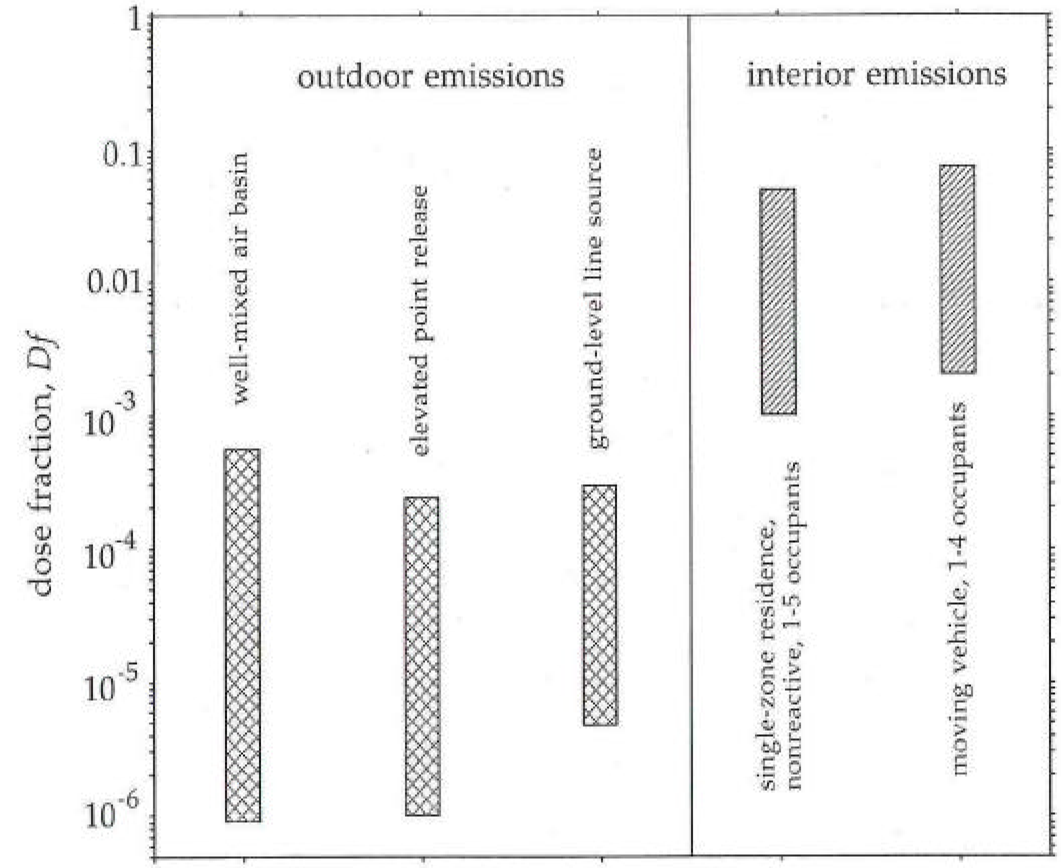
A typical pollutant release indoors is 1000 times as effective in causing human exposure as the same scale release to urban outdoor air.

- ETS $Df \sim 55 \times 10^{-4}$
- MV $Df \sim 12 \times 10^{-6}$

$\Rightarrow$ ETS Df / MV $Df \sim 450$

* KR Smith. See e.g., Air Pollution: Assessing Total Exposure in the United States, *Environment*, **30**(8): 10, 1988.

SUMMARY OF DOSE FRACTION RESULTS

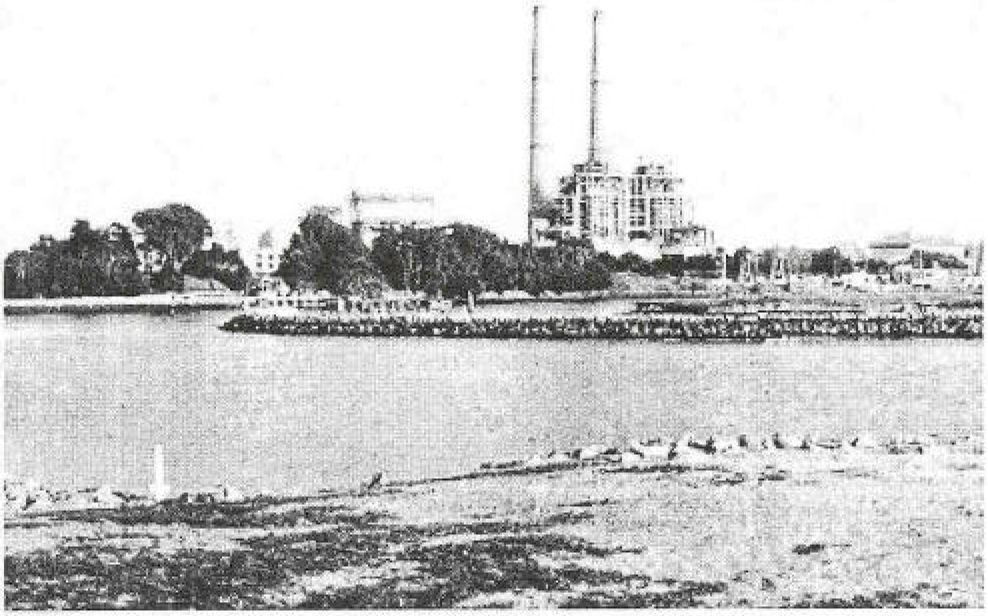


Source: ACK Lai et al., Inhalation transfer factors for air pollution health risk assessment, *J. Air Waste Management Assoc.*, **50**(89): 1688-1699, 2000.

ONGOING WORK: MOTOR VEHICLE DOSE FRACTIONS

- Dose fraction determined from "tracer" data
  - benzene
  - carbon monoxide
- Contributions of microenvironments
  - in-vehicle exposure
  - attached garages
  - proximity to major roadways
- Dose fractions determined from urban airshed modeling
- Environmental justice?
  - do *iDf*s vary significantly with socioeconomic status?

PLANNED WORK: EXPOSURE IMPACTS OF DG



- Distributed generation of electricity: shift emissions from few large, remote central stations to many small, local sources.

SUMMARY & CONCLUSIONS

- Virtues:
  - transparent
  - flexible
  - linkage to controls: source-to-dose
- Caveats:
  - near-source contributions
  - pollutant decay
  - secondary pollutants
- Development opportunities
  - modeling evaluations of dose fractions
  - experimental evaluations of dose fractions
  - applications for health-risk assessment

ACKNOWLEDGEMENTS

- Funding
  - DOE CB/NN
  - USEPA

- Students and staff
  - Dr. Alvin CK Lai
  - Dr. TL Thatcher
  - Garvin Heath
  - Dr. WJ Riley
  - Julian Marshall

- Colleagues and scholars
  - Tom McKone (right tool for the job)
  - Kirk Smith (exposure efficiency concept)
  - Adrian Bejan (maximize information per unit effort)
  - Lance Wallace (VOC exposure apportionment)